12

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FINAL REPORT

# EJECTION SEAT TESTING FOR FEMALES

TEST TRACK DIVISION

6585TH TEST GROUP

HOLLOMAN AIR FORCE BASE, NEW MEXICO





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**ARMAMENT DIVISION**

**AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE**

EGLIN AIR FORCE BASE, FLORIDA

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Anthropometric data from a recent survey of female pilots was analyzed and compared with available DoD anthropometric surveys. The comparison showed the two populations to be of different distributions, pointing out the deficiency in using the DoD survey in designing escape system tests covering female aviators. Further, analysis of two existing anthropometric surveys of male aviators taken in 1950 & 1967 found a considerable change in seventeen years, indicating a need for a

Block #20 (continued)

new survey of the contemporary population. Recommendations were made to change Military Standards and Specifications on ejection system and ejection systems testing to reflect inclusion of female aviators.

# PREFACE

The authors are deeply grateful for the help and cooperation of the Air Training Command. Without their assistance this entire study would have ended inconclusively. We especially want to thank the Director of Professional Services, Col Richard S. Malone, also Major Rodger W. Dennes, and SMS Joseph Mitchell, all of Headquarters Air Training Command, Randolph AFB.

We are also most thankful for the help of those personnel who prepared the field reports. In particular: SSgt Michael A. Samuel, NCOIC, Flight Medicine, Mather AFB; TSgt Ronald S. MacLelland, NCOIC, Aeromedical Services, Williams AFB; the USAF Clinic, Vance AFB; Mr Lawrence Walker, Health Technician, Laughlin AFB; the USAF Hospital, Columbus AFB; and the USAF Hospital, Reese AFB.

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# INTRODUCTION

MIL-S-9479B (ref 1) provides USAF agencies with design specifications for the design, development, and qualification testing of ejection and extraction seats for USAF aircraft. Further guidance for testing is available in MIL-STD-846C (ref 2). Both documents explicitly require the system meet performance specifications when tested with dummies simulating fifth and ninety-fifth percentile personnel.

The gender of the personnel is not specified in either document. At the time of publication of each document, all pilots who flew in aircraft with ejection/extraction systems were male. With the admission of females to Undergraduate Pilot Training (UPT), this is no longer valid. Female pilots ultimately destined for other types of aircraft are being trained in T-37 and T-38 aircraft. Class III crew members of both sexes, who are permitted a wider range of weights and heights than pilots, are flying in other high performance aircraft with ejection seat systems.

In addition, the standards need an updated data base from which to determine weights for flying personnel - of either gender.

We asked the Air Training Command to provide us the statures, weights, and sitting heights, where available, of their female flying personnel. We understood that these measurements already existed and that it was only a matter of assembling them.

We received excellent cooperation from the Air Training Command as we have previously acknowledged. They sent us the statures and weights of the 109 females which constituted their entire female flying population. Also, they provided us with 40 of the sitting heights. These data were obtained from Columbus, Laughlin, Mather, Reese, Vance, and Williams Air Force Bases using both rated and student personnel.

## PURPOSE

The purpose of this report is to address the validity of current test methods vis-a-vis the inclusion of females in the flying population and the inadequacy of current anthropometric surveys in representing the present flier of either gender. As a test agency, the 6585 Test Group will use the results to specify and procure anthropometric dummies for use in testing aircraft emergency egress systems.

## APPROPRIATE DEPARTMENT OF DEFENSE DOCUMENTS

There are many DoD documents which address different aspects of this problem. Several which appear most germane are listed below.

1. MIL-STD-846C is the previously mentioned document governing testing of ejection/extraction systems.

2. MIL-S-9479B is actually a specification for designing an ejection seat. This specification and MIL-STD-846C both specify use of 5th and 95th percentile dummies in testing.

3. AFSC Design Handbook 1-3 (ref 3) is a human factors engineering document which is designated in MIL-S-9479B as the reference document for anthropometric data on Air Force personnel. It contains results from anthropometric surveys for measurements of population parameters such as stature, sitting height, weight and other parameters relevant to system design.

4. DoD Handbook 743 (ref 4) is a summary and bibliography of several anthropometric surveys and points to two other official Department of Defense anthropometric data documents - MIL-STD-1472 (ref 5) and MIL-Handbook 759 (ref 6).

5. MIL-STD-1472 is the only official DoD source which contains anthropometric data on female personnel. It is limited to the 5th and 95th percentile values for selected body dimensions.

6. AFR 160-43 (ref 7) specifies the maximum and minimum dimensions which personnel must meet in order to be accepted into pilot training.

## SURVEYS

Of the many anthropometric surveys available, four are most germane to the question at hand.

1. In 1954 Hertzberg, et al., published the results of a 1950 survey of 4063 male fliers, including all crew members of different types of aircraft (cargo, bombers, fighters, etc)(ref 8).

2. In 1967 Churchill, et al. conducted another survey of male fliers with a sample population of 2420. The unpublished USAF Systems Command anthropometric data was summarised in later publications (refs 9 and 10).

3. In 1972 Clauser published the results of a survey of 1905 female Air Force personnel including officers, enlisted and basic trainees (ref 11).

4. In 1982 Mr. Gragg requested data from the Air Training Command on the stature, weight and sitting height of females currently flying in T-37 and T-38 aircraft, either as trainees in UPT or flying as Instructor Pilots. ATC responded by sending data on the entire population at that time - 109 women. The raw data of that population is presented in Appendix A. Results of calculating the frequency ogive are presented in Table I.

To determine the effect of time on changes in population parameters, one anthropometric dimension (weight) was chosen and compared using a Chi-squared test to determine if the distribution of that parameter remained constant. The procedures used were:

1. Data from DoD Handbook 743 were used to construct the frequency ogives for the 1950 and 1967 male surveys. (Neither variable distribution was Gaussian.) These ogives are shown in Appendix B.

2. The percentage of the population falling in six selected weight classes were determined from the ogives.

3. The number of expected and observed occurrences were determined by arbitrarily selecting a population of 100 from each survey. The 1967 survey was labelled the reference (expected) frequency and the 1950 survey was the observed.

## TABLE 1. FEMALE PILOT PARAMETERS

### GRAGG/ATC SURVEY

| STATURE | | WEIGHT | | SITTING HEIGHT | |
|---|---|---|---|---|---|
| % | INCHES | % | POUNDS | % | INCHES |
| 5 | 64.0 | 5 | 114.5 | 5 | 33.6 |
| 10 | 64.0 | 10 | 116.9 | 10 | 34.0 |
| 15 | 64.1 | 15 | 120.4 | 15 | 34.0 |
| 20 | 64.5 | 20 | 122.8 | 20 | 34.0 |
| 25 | 64.9 | 25 | 123.3 | 25 | 34.5 |
| 30 | 65.0 | 30 | 125.0 | 30 | 34.5 |
| 35 | 65.0 | 35 | 126.0 | 35 | 34.5 |
| 40 | 65.5 | 40 | 128.0 | 40 | 34.5 |
| 45 | 65.5 | 45 | 129.0 | 45 | 34.8 |
| 50 | 66.0 | 50 | 130.0 | 50 | 34.9 |
| 55 | 66.0 | 55 | 131.0 | 55 | 35.0 |
| 60 | 66.5 | 60 | 134.0 | 60 | 35.0 |
| 65 | 67.0 | 65 | 135.0 | 65 | 35.0 |
| 70 | 67.0 | 70 | 138.3 | 70 | 35.4 |
| 75 | 67.5 | 75 | 141.0 | 75 | 35.8 |
| 80 | 68.0 | 80 | 142.2 | 80 | 36.0 |
| 85 | 68.5 | 85 | 144.0 | 85 | 36.3 |
| 90 | 69.0 | 90 | 149.5 | 90 | 36.8 |
| 95 | 70.0 | 95 | 155.0 | 95 | 37.1 |

| Stature | Weight | Sitting Height |
|---|---|---|
| Mean: 66.2 | Mean: 131.8 | Mean: 35.0 |
| Std Dev: 1.94 | Std Dev: 12.19 | Std Dev: 1.07 |
| Range: 63.0 to 72.0 | Range: 102 to 166 | Range: 33.0 to 37.5 |
| N=109 | N=109 | N=40 |

4. The Chi-squared statistic was used to test the hypothesis that Ho: Distr(1967) = Distr(1950). Work sheets for these calculations are shown in Appendix B. The result of the test indicates that the hypothesis must be rejected at all levels of statistical significance. The populations as characterized by this parameter are statistically different and decisions for one population cannot be inferred by using statistics from the other.

A similar comparison for females was performed between the 1968 survey by Clauser and the Gragg/ATC survey of 1982. The same procedures were used except:

1. The observed frequencies are those reported in the Gragg/ATC survey.

2. The expected frequencies are based on the ogive for the Clauser survey. (Source data were found in DoD Handbook 743.)

Work sheets are provided in Appendix C. Again both populations were non-Gaussian distributed.

The test result again indicates that the hypothesis that the populations are the same must be rejected. The only available official anthropometric data on women does not represent the current female flying population.

This is not a surprising conclusion, because besides the 14 year difference in the surveys, the Gragg/ATC survey includes women who are required to meet AFR 160-43 which would tend to eliminate women who are small and slender. (In the current population, there were a few women flying with waivers for minimum weight or height.) In fact, if the 1968 survey is used, only women exceeding the 55th percentile in stature and 60th percentile in sitting height would be admitted into UPT, per AFR 160-43. The minimum weight permitted by AFR 160-43 corresponds to a 6th percentile in the 1968 survey. (Note that there no is such thing as a "fifth percentile female". The percentiles refer to population parameters and an individual who is 50th percentile in stature would only coincidentally be 50th percentile in any other parameter.)

DISCUSSION

The principal questions addressed in this report actually lead to a number of questions implicit to the issues. For example, given that MIL-STD-846C and MIL-S-9479B specify testing with 5th and 95th percentile dummies, does this imply that it is only cost effective to include the middle 90 per cent of the population? If so, 90 percent of what? From AFR 160-43, Class III fliers can be as tall as 80 inches with weights as high as 265 lb. Or they may be as short as 60 inches and as light as 92 lb. For Class I, IA or II, the range of weights is from a 103 lb female to a 241 lb male. As shown above, the weights found in AFSC DH 1-3 reflect a 1967 population and probably are not representative of a 1982 population (as indicated by the difference between 1950 and 1967 plus the inclusion of female fliers). The weights given in Section 2B11 of AFSC DH 1-3 are 140 lb for a 5th percentile and 211 lb for a 95th.

The ramification of considering the middle 90 per cent when testing ejection systems is best considered in light of failure mechanisms or more specifically, the phenomena that cause a system to fail to meet specifications. As mentioned above, weight is considered the most critical parameter in ejection testing, relative to stature, sitting height, etc. This is because the weight of the seat/dummy mass directly effects the acceleration of the system when the catapult or rocket is burning, whereas stature or sitting height affect only the location of the center of gravity of the seat/dummy mass. Small variations in stature or sitting height make almost negligible variations in the location of the c.g.

For light dummies, the most common failure mode found in testing is exceeding the Dynamic Response Index (DRI). The DRI is a model of expected compression of the spine due to acceleration along the spine.

For heavier occupants, the most critical point is being able to clear the tail of the aircraft. This failure phenomenon is not normally seen in track testing due to the relatively benign environment (zero sink/rise rate, zero roll and pitch, etc), but is a critical design factor in ejection systems. This end of the weight range is not changed significantly by addition of females.

So, this leaves only the low end of the weight spectrum which needs attention. The point to be resolved becomes how much of the light end of the spectrum to consider. If only the center 90 per cent of the population is to be considered in testing, over 70 percent of the current Air Force Class I/II female fliers would be below the minimum weights tested. Further, it seems imprudent to not anticipate a day when females are allowed in combat. If and when this eventuality occurs, the proportion of female aviators can be expected to increase substantially. The ejection systems being designed and tested today are the systems that will be in the field for the next two decades. So, if the females are not considered now, an untenable situation could result in the future. This leads to two further questions: 1) Are any additional costs incurred by considering lighter personnel, where costs can reflect technological risks as well as capital outlay? and 2) If the cost is sufficiently low, what data should be used to determine proper weights to test?

To address the cost question each aircraft with lightweight fliers needs to be checked individually to determine the effect of decreasing the Total Ejected Weight of an ejection system by 20 to 25 lbs. Now, in addition to the T-37 and T-38, this includes a few models such as the F-4 which carry Class III fliers as photographers, etc. To determine the effects on lighter fliers in existing aircraft requires more data than is available to the Test Track. Results of such a study might ultimately require retesting of some systems.

In the near future the T-46A will be introduced to replace the T-37 and T-38 as the prime USAF trainer so it should be given special attention. Current plans for the T-46A call for use of an ACES II ejection system, specifically one identical to or very similar to one tested here for the B-1 project. Data from those B-1 tests indicate a remarkable insensitivity of the DRI to the Total Ejected Weight for dummy weights from 135 to 210 lbs. This can be seen in Figure 1, a plot of maximum DRI's versus nominal ejection speed. Using the three weights tested (5th, 50th and 95th percentiles), as sample groups, the means were compared to determine if there was a significant difference. The test failed, i.e., there was no statistical difference in the sample means. (Sample sizes: 5th - 11, 50th - 2, 95th - 14)

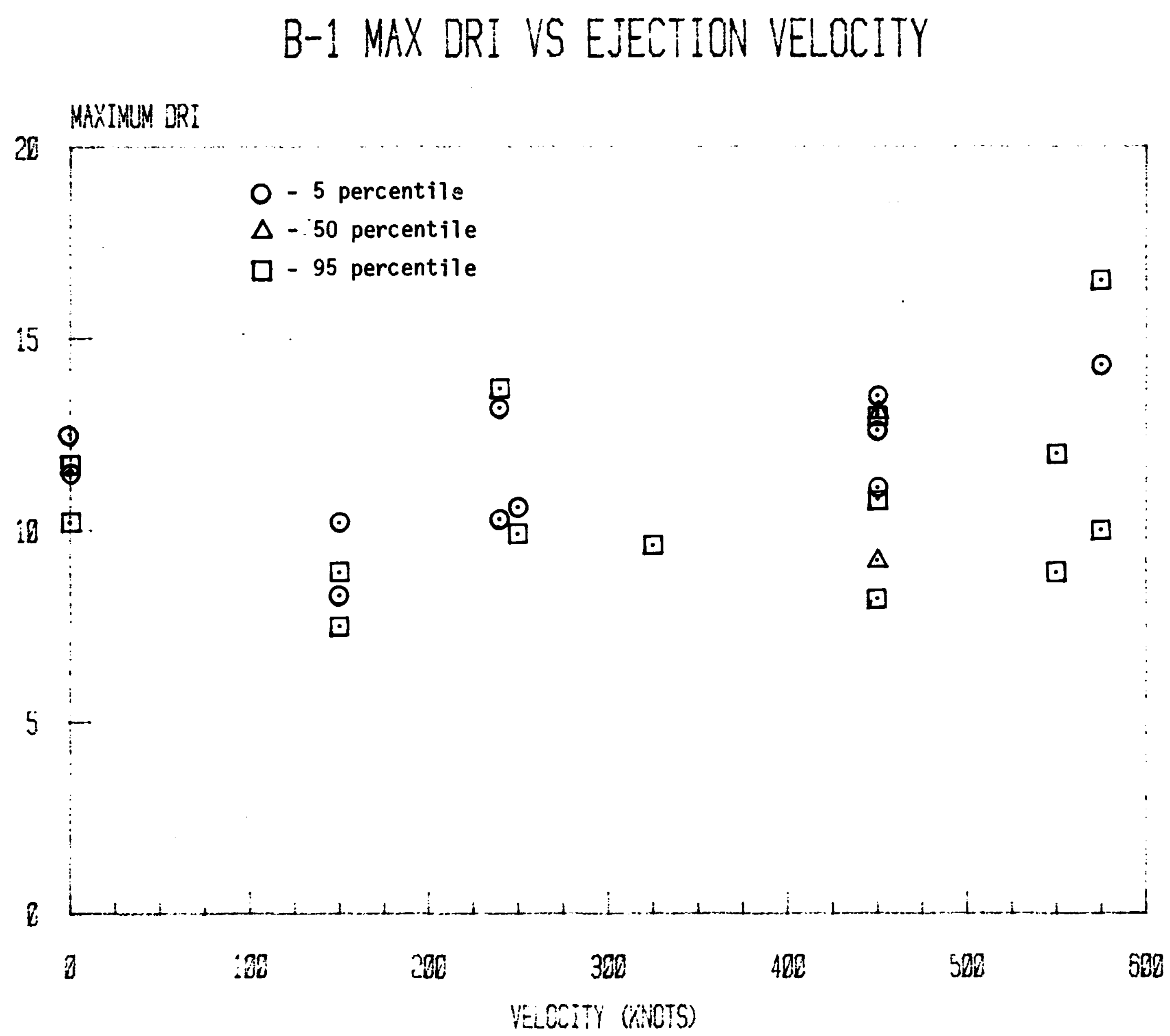
B-1 MAX DRI VS EJECTION VELOCITY
MAXIMUM DRI
○ - 5 percentile
△ - 50 percentile
□ - 95 percentile
20
15
10
5
0
0
100
200
300
400
500
600
VELOCITY (KNOTS)

Figure 1

Given this finding, it would seem that the technological risk of considering lighter fliers may be acceptably low if the B-1 data does not have to be extrapolated very far below the 135 lb 5th percentile male weight. This leads to the second major question, 90 percent of what?

The answer we propose is to test for 90 percent of the male pilots and 90 percent of the female pilots, considering the populations as separate and overlapping - 5th percentile female to 95th percentile male. Given that the data in AFSC DH 1-3 represents the most current survey of the male flying population, those data should be used to determine the upper end for testing. As a population for determining female parameters, we recommend that the results of the Gragg/ATC survey be used. This is a rather small sample as anthropometric surveys go (109 samples), but is a better indicator than the Clauser survey which included a random sample from a general Air Force female population, not just aviators.

This results in testing for pilots with weights from 114.5 lb to 211 lb, statures from 64 inches to 73.9 inches and sitting heights from 33.6 inches to 38.8 inches. This is a reduction of approximately 20 lbs in low-end weight from the B-1 data (25 from DH 1-3), 1.9 inches in stature, and 1.1 inches in sitting height. This degree of extrapolation is certainly the limit of prudence.

This approach results in testing for more than 90 percent of the flying population. But, this is applaudable if the technological risk is as low as may be indicated.

## CONCLUSIONS AND RECOMMENDATIONS

1. AFSC Design Handbook 1-3, the current document governing anthropometric parameters to which ejection systems should be tested, needs updating in two ways: first, it reflects only male parameters when there is an increasing female flying population; and second, the parameters listed for males are results of a survey taken fifteen years ago.

2. Our statistical tests indicate substantial changes in population parameters occurred in the seventeen years prior to the survey reflected in AFSC DH1-3. Given the potential for like changes since 1967, we recommend that a new survey of the flying population be made and that governing anthropometric documents be changed to reflect the contemporary population.

3. Given the inclusion of female pilots flying in ejection systems, we recommend that all future ejection system testing be conducted with anthropometric dummies which reflect stature and weight parameters ranging from the ninety fifth percentile male defined by AFSC DH 1-3 (until a new survey can be conducted) to fifth percentile females as defined by the Gragg/ATC survey of 1982.

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# APPENDIX A

## GRAGG/ATC SURVEY

| SUBJECT NO. | STATURE (IN.) | WEIGHT (LB.) | SITTING HEIGHT (IN.) |
|---|---|---|---|
| 1 | 72.0 | 166 | |
| 2 | 71.0 | 144 | |
| 3 | 71.0 | 130 | 37.25 |
| 4 | 70.0 | 155 | |
| 5 | 70.0 | 140 | 36.25 |
| 6 | 70.0 | 126 | |
| 7 | 69.5 | 150 | |
| 8 | 69.0 | 155 | |
| 9 | 69.0 | 155 | |
| 10 | 69.0 | 149 | |
| 11 | 69.0 | 144 | 36.5 |
| 12 | 69.0 | 138 | 37.5 |
| 13 | 69.0 | 130 | 37.0 |
| 14 | 69.0 | 125 | |
| 15 | 68.75 | 128 | |
| 16 | 68.5 | 141 | 37.0 |
| 17 | 68.5 | 130 | 36.0 |
| 18 | 68.5 | 123 | 35.0 |
| 19 | 68.0 | 148 | |
| 20 | 68.0 | 145 | |
| 21 | 68.0 | 143 | 34.5 |
| 22 | 68.0 | 129 | 34.75 |
| 23 | 68.0 | 124 | |
| 24 | 68.0 | 120 | 35.0 |
| 25 | 67.5 | 165 | 36.25 |
| 26 | 67.5 | 156 | |
| 27 | 67.5 | 142 | |
| 28 | 67.5 | 135 | |
| 29 | 67.5 | 120 | |
| 30 | 67.0 | 152 | 35.0 |
| 31 | 67.0 | 146 | 34.5 |
| 32 | 67.0 | 136 | |
| 33 | 67.0 | 134 | |
| 34 | 67.0 | 128 | |
| 35 | 67.0 | 127.5 | 34.5 |
| 36 | 67.0 | 126 | 34.0 |

| | | | |
|---|---|---|---|
| 37 | 67.0 | 125 | |
| 38 | 67.0 | 123 | |
| 39 | 66.75 | 111 | 35.0 |
| 40 | 66.5 | 150 | 36.0 |
| 41 | 66.5 | 150 | |
| 42 | 66.5 | 144 | 35.5 |
| 43 | 66.5 | 137 | 35.0 |
| 44 | 66.5 | 129 | |
| 45 | 66.5 | 124 | 35.5 |
| 46 | 66.0 | 140 | |
| 47 | 66.0 | 139 | |
| 48 | 66.0 | 135 | |
| 49 | 66.0 | 135 | |
| 50 | 66.0 | 131 | |
| 51 | 66.0 | 130 | |
| 52 | 66.0 | 129 | |
| 53 | 66.0 | 126 | |
| 54 | 66.0 | 123 | |
| 55 | 66.0 | 122 | 34.5 |
| 56 | 66.0 | 121 | |
| 57 | 66.0 | 116 | |
| 58 | 65.5 | 147 | 36.0 |
| 59 | 65.5 | 144 | |
| 60 | 65.5 | 142 | 34.75 |
| 61 | 65.5 | 141 | |
| 62 | 65.5 | 135 | |
| 63 | 65.5 | 130 | |
| 64 | 65.5 | 128 | |
| 65 | 65.5 | 126 | |
| 66 | 65.5 | 117 | |
| 67 | 65.5 | 113 | |
| 68 | 65.25 | 142 | |
| 69 | 65.0 | 144 | 35.0 |
| 70 | 65.0 | 142 | |
| 71 | 65.0 | 140 | |

| | | | |
|---|---|---|---|
| 72 | 65.0 | 135 | 34.5 |
| 73 | 65.0 | 135 | |
| 74 | 65.0 | 130 | 34.75 |
| 75 | 65.0 | 127 | |
| 76 | 65.0 | 125 | 34.0 |
| 77 | 65.0 | 123 | |
| 78 | 65.0 | 123 | 34.5 |
| 79 | 65.0 | 122 | |
| 80 | 65.0 | 114 | 34.0 |
| 81 | 65.0 | 104 | |
| 82 | 64.75 | 102 | 35.25 |
| 83 | 64.5 | 141 | |
| 84 | 64.5 | 136 | 34.5 |
| 85 | 64.5 | 133 | |
| 86 | 64.5 | 131 | |
| 87 | 64.5 | 125 | 34.0 |
| 88 | 64.5 | 122 | |
| 89 | 64.5 | 122 | |
| 90 | 64.5 | 120 | |
| 91 | 64.5 | 113 | 35.0 |
| 92 | 64.25 | 129 | |
| 93 | 64.0 | 134 | |
| 94 | 64.0 | 133 | 34.0 |
| 95 | 64.0 | 131 | 33.0 |
| 96 | 64.0 | 131 | |
| 97 | 64.0 | 130 | 33.5 |
| 98 | 64.0 | 126 | 34.0 |
| 99 | 64.0 | 123 | |
| 100 | 64.0 | 119 | |
| 101 | 64.0 | 119 | |
| 102 | 64.0 | 116 | |
| 103 | 64.0 | 116 | |
| 104 | 64.0 | 113 | |
| 105 | 63.5 | 125 | |
| 106 | 63.25 | 115 | |
| 107 | 63.0 | 134 | 34.5 |
| 108 | 63.0 | 129 | |
| 109 | 63.0 | 125 | 33.75 |

# APPENDIX B

## COMPARISON OF 1967 SURVEY AND 1950 SURVEY OF MALE USAF FLYING PERSONNEL

1. 1950 SURVEY RESULTS

| Upper Bound Of Interval | Relative Percentage | Cumulative Percentage | Frequency Of Occurrence |
|---|---|---|---|
| 70 kg | 0.35 | 0.35 | 100 x .35 = 35 |
| 75 kg | 0.20 | 0.55 | 20 |
| 80 kg | 0.19 | 0.74 | 19 |
| 85 kg | 0.11 | 0.85 | 11 |
| 90 kg | 0.09 | 0.94 | 9 |
| infinity | 0.06 | 1.00 | 6 |
| Total | 1.00 | | 100 |

2. 1967 SURVEY RESULTS

| Upper Bound Of Interval | Relative Percentage | Cumulative Percentage | Frequency Of Occurrence |
|---|---|---|---|
| 70 kg | 0.19 | 0.19 | 100 x .19 = 19 |
| 75 kg | 0.21 | 0.40 | 21 |
| 80 kg | 0.19 | 0.59 | 19 |
| 85 kg | 0.16 | 0.75 | 16 |
| 90 kg | 0.11 | 0.86 | 11 |
| infinity | 0.14 | 1.00 | 14 |
| Total | 1.00 | | 100 |

3. Calculate the Chi-squared statistic by the formula

$$\chi^2 = \sum_{i} \frac{(o_i - e_i)}{e_i}$$

where k = number of intervals
$o_i$ = observed
$e_i$ = expected

$$\chi_c^2 = 20.02$$

Note: Degrees of freedom to be used with this determination is

d.f. = (k-1)-p

where k = number of intervals
p = number of parameters estimated from data.

d.f. = (6-1)-1 = 4

$\chi_c^2 > \chi_{\alpha,4}^2$ for all values of $\alpha$ of statistical interest. Therefore, reject the hypothesis that the two distributions are equal.

## APPENDIX C

## USAF WOMEN (1968) COMPARED TO

## GRAGG/ATC SURVEY OF WOMEN FLIERS (1982)

1. The data for the *USAF Women (1968)* survey is taken from reference 4, page 441. This is used as the reference to determine the "expected" values for use in the Chi-squared evaluation.

2. The "observed" values are those values found in the Gragg/ATC survey of women fliers. The raw data for that survey are in Appendix A.

3. Evaluation of the hypothesis

$$H_0: D_o = D_e$$

| Upper Bound Of Interval | Cum Freq | Rel Freq | Expected | Observed |
|---|---|---|---|---|
| 50 kg | 0.155 | 0.155 | 16.895 | 2 |
| 56 kg | 0.445 | 0.290 | 31.61 | 26 |
| 60 kg | 0.650 | 0.205 | 22.345 | 34 |
| 66 kg | 0.865 | 0.215 | 23.432 | 33 |
| 70 kg | 0.940 | 0.075 | 8.175 | 8 |
| infinity | 1.000 | 0.060 | 6.540 | 6 |
| Total | | 1.000 | 109.000 | 109 |

$$\chi^2_c = 24.2$$

d.f. = 4

Reject $H_0$ at all levels of significance. The distribution of weights obtained by polling the existing population of female fliers in Air Training Command is significantly different from the distribution of female weights contained in MIL-STD-1472 (or DoD Handbook 743).